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Investigation of the Effects of Different Percentages of Synthetic Fibers on Triaxial Compressive Strength

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Abstract: *The current study aimed at investigation of the effects of the application of synthetic polymer fibers in the concrete with natural sand. In order to evaluate the construct behavior of fiber-reinforced concrete with the natural and recycled aggregates, some of its properties such as the triaxial compressive strength were theoretically studied. In addition, different types of fibers and their chemical and physical properties, as well as different types of fiber-reinforced concrete with and without the recycled aggregates were dealt with for better recognition of fiber-reinforced concretes. In the following, through performing the related tests for the determination of the triaxial compressive strength on the concrete with polymer fibers containing the natural aggregates and combination of recycled and natural aggregates as coarse aggregates, and the concrete without fibers containing the natural aggregates and combination of recycled and natural aggregates as coarse aggregates, the use of these aggregates has been studied. The results showed that the use of synthetic fibers in concrete would lead to the increase in tensile strength, and to some extent, in triaxial compressive strength. Also, the decrease in tensile strength of the concrete with recycled aggregates can be somehow compensated by adding the fibers, and besides, the addition of the fibers to the recycled concrete would lead to the improvement of the mechanical properties of the concrete such as the compressive strength, tensile strength, and also, the triaxial strength.*

Keywords: *Synthetic Fibers, Compressive Strength, Triaxial Compressive Strength*

INTRODUCTION

The fiber-reinforced concrete technology is another example of the use of composites as a modern technology in the construction industry. Among the new materials that has a special position in construction is the reinforcing fibers. These fibers which more include glass, polypropylene, steel, and sometimes carbon, are highly used in making the fiber-reinforced concretes. Also, the glass fibers can be used in the light and very corrosion-resistant armatures. The fiber concrete is actually a type of composite and with reinforcing fibers in the concrete, its tensile and compressive strength is greatly increased. This composite mixture has a proper consistency and integrity and makes it possible to use the concrete as a formable material to be used for the production of fully curved resistant surfaces. The fiber-reinforced concrete has also a high energy absorption capability and does not break under the shock load. The historical evidence of this technology is the use of thatch in buildings. In fact, the fiber-reinforced concrete is the advanced type of this technology, in which the natural and artificial fibers replace the straw and the cement replaces the mud in the thatch. The studies have shown that different kinds of fibers are used for reinforcing (arming) the cement-based matrixes. The fibers may be artificial organic substance (such as the polypropylene or carbon), nonorganic (such as the steel or glass), natural organic substance (such as the cellulose or sisal), or non-organic natural substance (such as asbestos). Currently, only the steel, glass, polypropylene, and polyester are widely used in concrete buildings industry of the United States. The concrete reinforced by the acrylic fibers also, despite being used in Europe for many years, have just entered the U.S. market. Besides, although the asbestos cement products have been widely used in the past, other cement-based products due to the health risks arose from the asbestos fibers have rapidly replaced these products. The organic natural fibers, due to the economic considerations, are a common type of reinforcing in the developing countries. Today, by the use of glass fibers, polypropylene, steel, and sometimes carbon, the production of different kinds of composite concretes in different industrial applications has been possible, and the use of them has been accepted by the building industries in many advanced countries. It has been revealed so far that different types of fibers can increase the concrete's buckling strength, impact resistance, energy absorption, abrasion resistance, and tensile strength. Among the most important variables that affect the fiber-reinforced concrete properties are the concrete matrix properties, fibers efficiency, and the amount of fibers. The resistance and endurance are two main factors in the hardened concrete, and the higher the concrete's compressive strength gets, the more fragile it becomes, and consequently, its tensile strength is not increased proportionate to its compressive strength. Also, its buckling strength would be lower. Therefore, the need for the use of fibers in the concrete in order to increase the tensile strength and prevent the crack expansion and especially the softness, is quite obvious, and the increase in this value depends on the strength of the concrete without fiber, the form of the fiber, and its percentage. Regarding what was mentioned, the fibers used must have a high tensile strength and an optimal formability. The fibers endurance in the concrete and adhesion between the concrete and the fibers are also among the important matters that should be taken into consideration. The length of the fibers plays an important role in its performance. The excess length of the fibers would lead to the balls and lumps when mixing and since the balls are loosened against the tensile stress, the concrete loses its ability against the stresses. On the other hand, if the fibers are shorter than what they are supposed to be, the proper adhesion between the concrete and the fibers is not created and consequently, the fibers are removed out of the concrete due to the tension. Therefore, the fibers must have a specified length-to-diameter ratio. The optimal length-to-diameter of fibers is called the 'apparent ratio', which ranges from 120 to 150 for some fibers. In addition, in order to increase the fibers adhesion to the cement, methods such as spinning the fibers, wrapping the two ends of fibers, etc. have been considered. So far, it has been revealed that different types of fibers can increase the concrete's buckling strength, impact resistance, energy absorption, abrasion resistance, and tensile strength. Therefore, in the mixtures modified by the fibers, the tensile strength, the flexural strength, flexibility, and crack control are improved. The most important factors controlling the performance of the mixed materials are 1) the physical properties of the reinforcers and the matrix, and 2) the bond strength between the reinforcer and the matrix (Hannant, 1978). Based on the studies, although the principles dominating the structures of the normal and fiber-reinforced concretes are the same, there are differences in terms of specifications as follows: 1) the fibers are distributed all over the given cross section while the bars and cables are placed only in the areas needed, 2) compared to the bars, most of the fibers are short and have close distance. The studies have shown that generally, it is not possible to, similar to the bars networks or the reinforcement cables, achieve a high ration of reinforcement (the ratio of reinforcement area to the concrete area) by the use of fibers (Ramachandran et al., 1981; Hannant, 1978). The type of the fibers and their volumetric percentage in the concrete affects the mechanical properties of the fiber-reinforced concretes. Overall, it can be said that the rate of improvement in the fiber-reinforced concrete properties compared to the concrete without fibers depends on the type of the fibers and its amount (Concrete Society Technical Report, 2011). The research show that presence of polymer fibers is not such effective on the concrete compressive strength, but due to the role of fibers in stitching the cracks, prevent the brittleness and crushing of the cement. In fact, the fiber-reinforced concrete compression failure is accompanied by formability and the samples maintain their adherence until the rupture (Bayasi & Zaccarello, 2010). In this regard, Soroushian and Bayasi (1991) investigated the effects of different types of polymer fibers on the compressive behavior of the concrete (Soroushian & Bayasi, 1991). Li et al. (1998) have also shown that the direct compressive strength of the concretes containing 2% volumetric percentage of polymer fibers is 10% higher than the concretes without the fibers, and the fiber-reinforced concrete has a higher formability compared to the concrete without fibers. By the increase in the fibers to 3%, the tensile strength of the concrete is significantly increased and the fiber-reinforced endurance is notably higher than the fiberless concrete (Li et al., 1998). Olivito and Zuccarello (2010) investigated the effects of the polymer fibers with different lengths on the direct tensile strength of the concrete. The obtained results showed that the use of short fibers increases the maximum tensile strength, while using long polymer fibers improves the ultimate strain (Olivito and Zuccarello, 2010). Thus, the current study aimed at the investigation of the effects of different synthetic fibers percentages on the triaxial compressive strength.

Methodology

Since the current study aimed at the investigation of the effects of different synthetic fibers percentages on the triaxial compressive strength, the triaxial strength testing device with a capacity of 700 bar was used for testing in the current study. The used materials also included: fine-grained natural aggregates (gravel), coarse natural aggregates (sand), coarse recycled aggregates (sand), type II Portland cement, microsilica, super lubricant, water, and the synthetic fibers. The river washed sand is used in the current study, which was collected from Anakhatoun's Diamond Sand Mine in Tabriz. The specific gravity of this sand in the 1SSD mode is 2500 kg/m^3, with a water absorption of 4% and moisture of 0.88%. The grading of the used sand has been done according to the ASTM C33-84. The natural sand used in the current study is also river-based which has been collected from Anakhatoun's Diamond Sand Mine. This rounded-corner sand has a uniform grading with gravels with a maximum size of 25 mm. This natural sand has a specific gravity of 2630 Kg/m^3 in the SSD mode, the water absorption of 0.85%, and the moisture of 0.35%. In order to collect the crushed concrete for the tests, the crushed concrete with the specified primary quality related to the rods under the loads with an average compressive strength of 300kg/cm^2, located in the Maghbarat Al-Shoara street in Tabriz City, were collected. The concrete was manually crushed to the gravels smaller than 25mm in the laboratory, on which the grading, water absorption, moisture percentage, and bulk specific gravity tests were performed. In addition, in the current study, the synthetic polymer fibers with diameter of 0.1 mm and length of 38 mm in a waved form and with the specific gravity of 0.91-0.94 g/cm^3 were used. More details on the mechanical and physical properties of these fiber are provided in the following table:

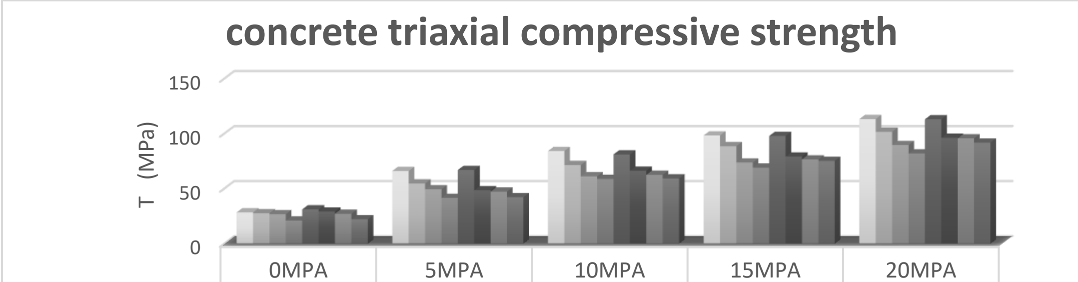
Table 1: the physical and mechanical properties of the used fibers

Thickness	Length	Length-to-diameter ratio (L/D)	Tensile strength (Mpa)	Elasticity module (Mpa)	Specific gravity (gr/cm^3)	Apparent form	Fibers
0.5mm	38mm	76	800	7000	0.94	Waved	Polymer

The mixer used in the current study was of a rotating type with the maximum volume of 120 liters. The material mixing procedure is as follows: firstly, the dry material (gravel and sand) are loaded into the mixer to be mixed for 3 minutes. The primary computational water for making the aggregates SSD is poured into the mixer and they are mixed completely with each other for 2 minutes. Then, the cement materials are gradually added to the mixer and the second computational water along with the super lubricant are added to the mixer, so that the material lumps would be prevented, and they are mixed well. Finally, the polymer fibers are slowly added to the mixer, to be mixed for 5 minutes. The Hoek Cell has a body of steel with two spherical steel seats with a hardness of 58HRC and its internal rubber membrane along with a hydraulic jack to set the confinement strength by the hydraulic oil between the membrane and body. In this method, the samples are loaded inside the rubber membrane and the two steel seats confine the concrete sample. The testing procedure is as such that after the placement of the sample inside the Hoek Cell, firstly, the lateral pressure is increased to a specified amount by the hydraulic jack and the oil between the body and membrane. Then, a standard press loads the sample until the lateral pressure is dropped. In case a high lateral pressure, for example 20 MPa, is intended before loading, the lateral pressure is initially increased to a specified value, for example 5 MPa, and then the loading starts, and in line with pace of the loading, the lateral pressure is increased to 20 MPa, and it is fixed until the moment that the sample is broken. According to the ASTM C801-98 standard's recommendation, the loading speed should be considered as 241±103 kPa/s, and in the current study, it has been considered to be 300 kPa/s.

Findings:

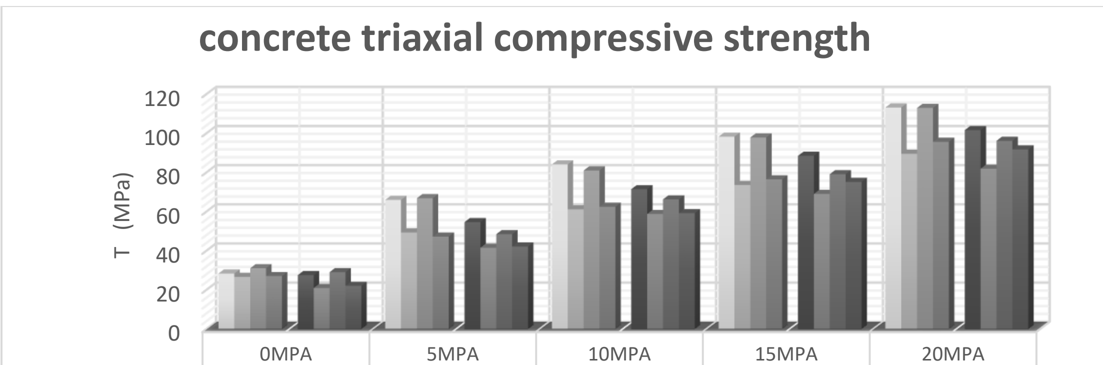
Based on the below charts, it is quite obvious that in the 0.5% volumetric fibers designs, in both natural and recycled concretes, the triaxial compressive strength has been decreased, compared to the control designs of the same materials (H1 and H2). However, by the increase in the fibers volume to 0.75% of the volumetric percentage, the triaxial compressive strength is increased for both natural and recycled concretes, but this increasing trend has been stopped for designs with 1% volumetric percentage of the fibers in both natural and recycled concretes, and we can see a decreasing trend in triaxial compressive strength. The H7 design in natural concrete and the H8 in the recycled concrete in the confinement pressures of 5, 10, 15, and 20 MPa, have the highest triaxial compressive strength, which indicates that for achieving the highest compressive strength, the 0.75% volume of the synthetic fibers is the most optimal percentage.



	0MPA	5MPA	10MPA	15MPA	20MPA
H1-F0N	28.3	65.9	84.05	98.2	113.1
H2-F0R	27.5	54.55	71.35	88.45	101.55
H3-F0.5N	26.6	49.3	61.1	73.55	89.5
H4-F0.5R	20.9	41.45	58.7	68.95	81.85
H7-F0.75N	31	66.8	80.95	97.8	112.9
H8-F0.75R	29	48.4	66.15	79.05	96.1
H5-F1N	27	47.15	62.4	76.4	95.6
H6-F1R	22	42.1	59.15	75.1	91.7

H1-F0N H2-F0R H3-F0.5N H4-F0.5R H7-F0.75N H8-F0.75R H5-F1N H6-F1R

Chart 1: the effects of the fibers on concrete triaxial compressive strength with fixed lateral pressure



	0MPA	5MPA	10MPA	15MPA	20MPA
H1-F0N	28.3	65.9	84.05	98.2	113.1
H3-F0.5N	26.6	49.3	61.1	73.55	89.5
H7-F0.75N	31	66.8	80.95	97.8	112.9
H5-F1N	27	47.15	62.4	76.4	95.6
H2-F0R	27.5	54.55	71.35	88.45	101.55
H4-F0.5R	20.9	41.45	58.7	68.95	81.85
H8-F0.75R	29	48.4	66.15	79.05	96.1
H6-F1R	22	42.1	59.15	75.1	91.7

H1-F0N H3-F0.5N H7-F0.75N H5-F1N H2-F0R H4-F0.5R H8-F0.75R H6-F1R

Chart 2: the effects of the fibers on concrete triaxial compressive strength with fixed lateral pressure

Table 2: the values of increase or decrease in the triaxial compressive strength in the fiber-reinforced concrete compared to the fiberless concrete

The effects of the fibers on triaxial compressive strength							
	H1-F0N	H3-F0.5N		H7-F0.75N		H5-F1N	
	T (MPa)	T (MPa)	Increase or decrease percentage	T (MPa)	Increase or decrease percentage	T (MPa)	Increase or decrease percentage

0MPA	28.3	26.6	-6.01	31	9.54	27	-4.59
5MPA	65.9	49.3	-25.19	66.8	1.37	47.15	-28.45
10MPA	84.05	61.1	-27.31	80.95	-3.69	62.4	-25.76
15MPA	98.2	73.55	-25.10	97.8	-0.41	76.4	-22.20
20MPA	113.1	89.5	-20.87	112.9	-0.18	95.6	-15.47
	H2-F0R	H4-F0.5R		H8-F0.75R		H6-F1R	
	T (MPa)	T (MPa)	Increase or decrease percentage	T (MPa)	Increase or decrease percentage	T (MPa)	Increase or decrease percentage
0MPA	27.5	20.9	-24.00	29	5.45	22	-20.00
5MPA	54.55	41.45	-24.01	48.4	-11.27	42.1	-22.82
10MPA	71.35	58.7	-17.73	66.15	-7.29	59.15	-17.10
15MPA	88.45	68.95	-22.05	79.05	-10.63	75.1	-15.09
20MPA	101.55	81.85	-19.40	96.1	-5.37	91.7	-9.70

Conclusion:

Regarding the results of the tests and analyses, it can be concluded that the use of synthetic fibers in the concrete can lead to the increase in the tensile strength, and somehow, in the triaxial compressive strength. In addition, the decrease in the tensile strength of the recycled concrete can be somewhat compensated by adding the fibers, and besides, addition of the fibers to the recycled concrete would lead to the improvement in mechanical properties of the concrete such as the compressive and tensile strength, as well as the triaxial strength. Thus, in this regard, the following suggestions are provided:

- Using different types of fibers in recycled concrete for improving the strength drop due to the use of recycled aggregates
- Analysis and investigation of the triaxial compressive strength by the Software
- Using the results of software analysis, and performing the traixial strength test for analysis of different types of confined concrete.

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